TS Cindy (2017): New insights on TC formation from CPEX Observations and Modeling.

CPEX Science Meeting
July 16th 2019
UW

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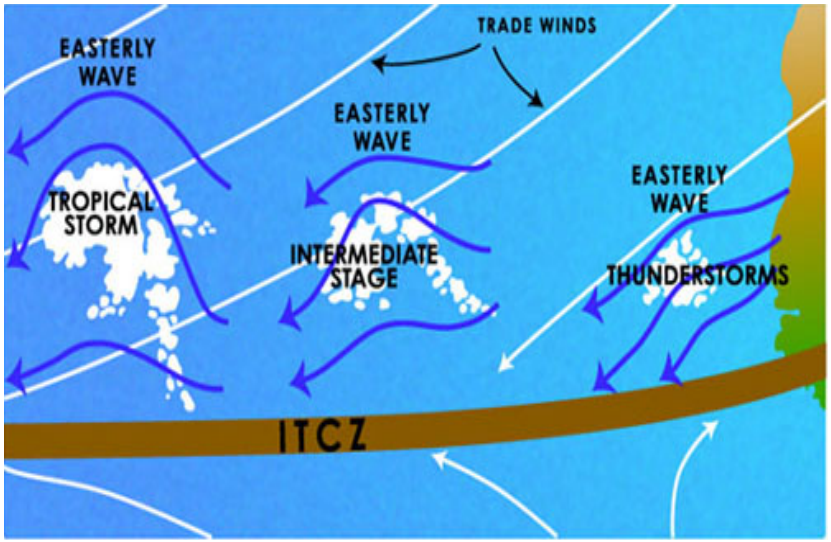
Outline

1. TC Genesis Overview
2. TS Cindy (2017)
3. Data and Methods
4. Results
5. Conclusions

TC Genesis – Multi Scale Process

- Large-scale conditions:
  - Pre-existing cyclonic vorticity (e.g. AEW)
  - Low vertical wind shear
  - Moist mid-troposphere
  - Warm, deep ocean mixed layer
  - Planetary vorticity



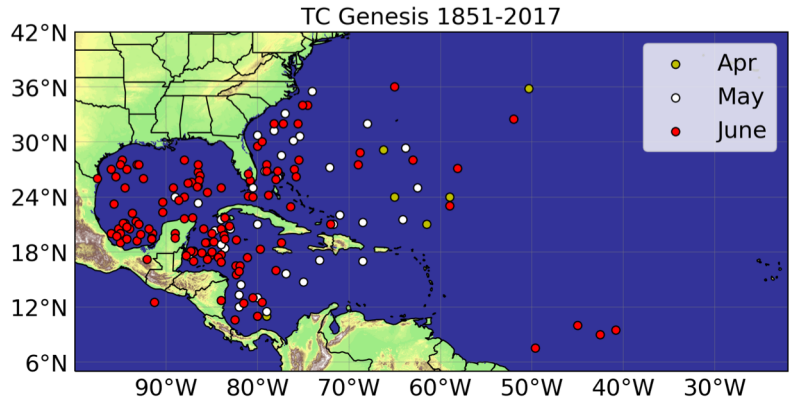
- Vortex scale:
  - Vorticity increase
  - Inner core warming.

- Mesoscale: deep convection, heat fluxes and (sometimes) subsidence.

‘Early Season’ Tropical Cyclones

- Many weak TCs in Gulf of Mexico/NW Caribbean in June.
- Large-scale environment not ideal
  - Large shear, dry air
  - SST below seasonal max
- Characteristic ‘look’

What processes can support TC genesis in a generally unfavorable environment?



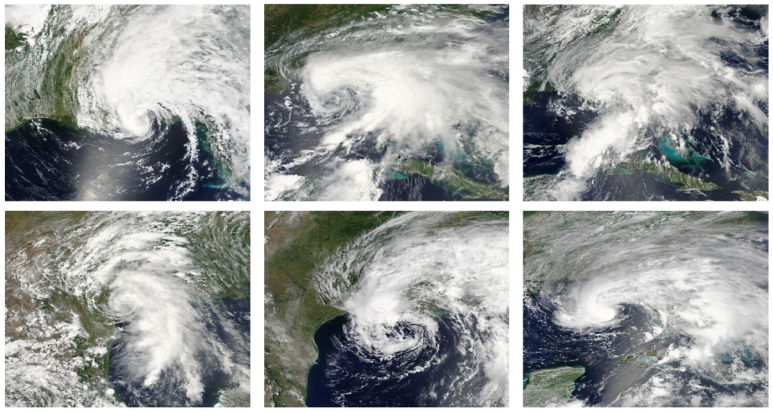


Figure 8. Visible imagery from top left to bottom right of TS Arlene (2005), TS Debby (2012), TS Andrea (2013), TS Bill (2015), TS Cindy (2017), ST Alberto (2018).

CPEX Case study: TS Cindy (2017)

- TS formation: 06/20 18 UTC
- Interaction

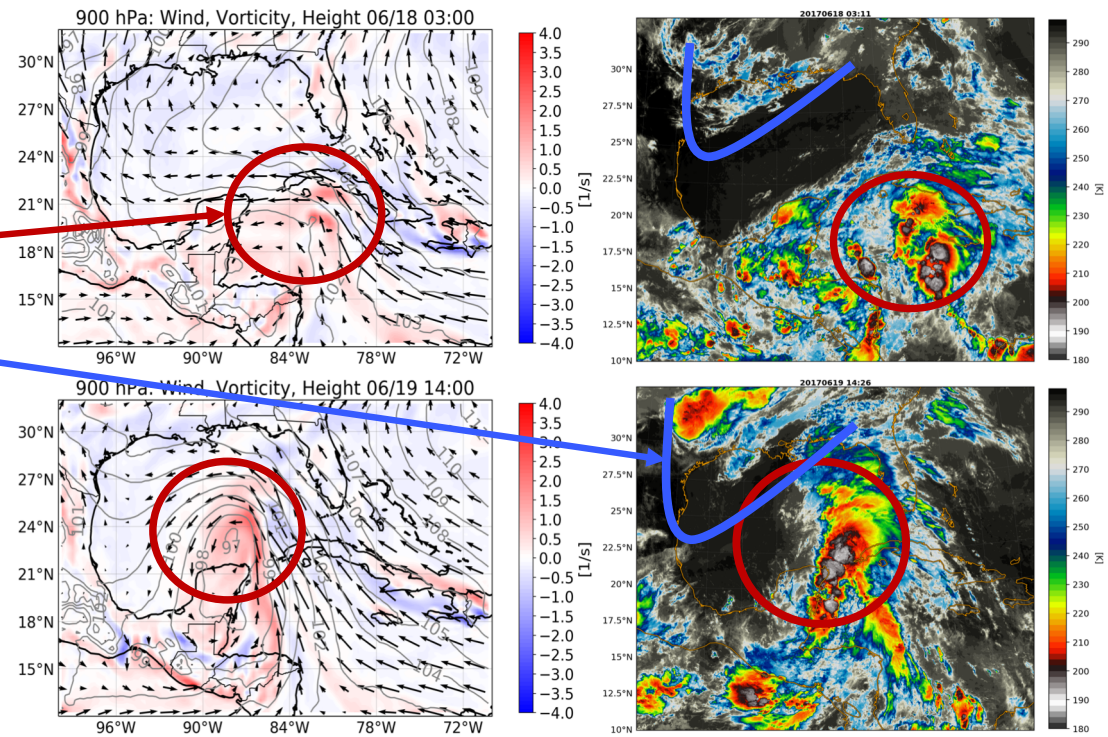
Tropical Wave

Upper-level trough

- Unfavorable environment:
  - Large wind shear
  - Dry mid-troposphere
  - Displaced convection.

ERA-5 Reanalysis

GOES-E IR



Data and Methods

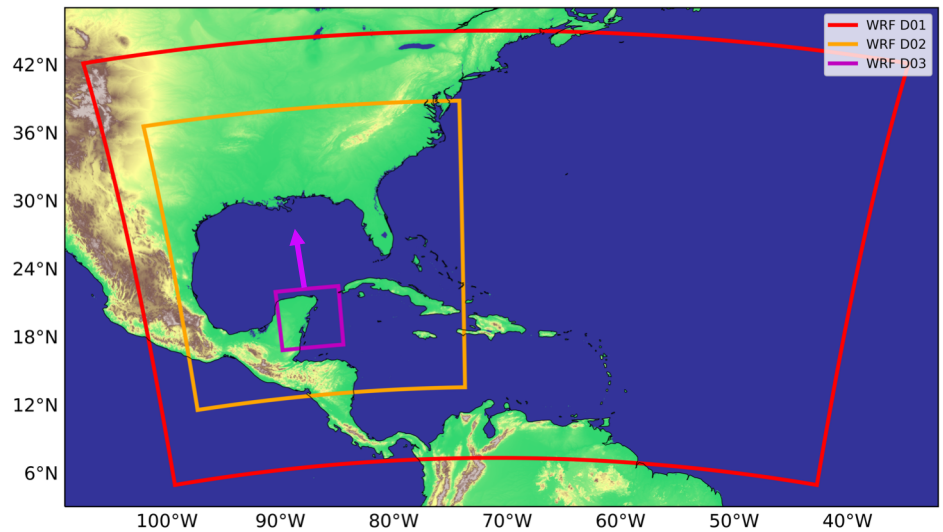
- Focus on June 20th CPEX mission.

- DC-8 Aircraft observations.
  - DAWN: 2-micron pulsed Doppler wind profiling lidar
  - Dropsondes: wind, thermodynamic profiles

- Fully-coupled atmosphere-wave-ocean simulation using UWIN-CM.
  - WRF atmosphere, UMWM waves, HYCOM ocean

UWIN-CM Experiment Set-up

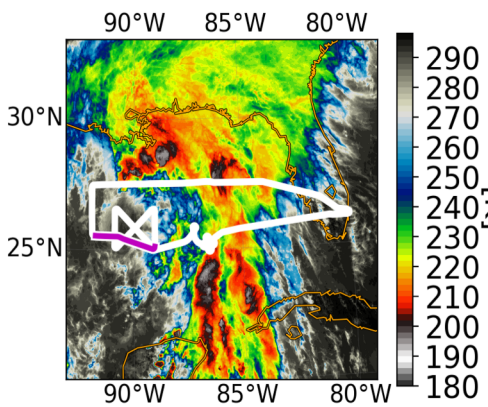
- Simulation: June 19th 12 UTC – June 23rd 00 UTC.
- WRF: 3 nested domains (12, 4, 1.3 km resolution). Inner most is storm-following.
- 4/1.3 km explicit convection
- UMWM, HYCOM: 4 km resolution
- Initial and boundary conditions: ERA-5 reanalysis.



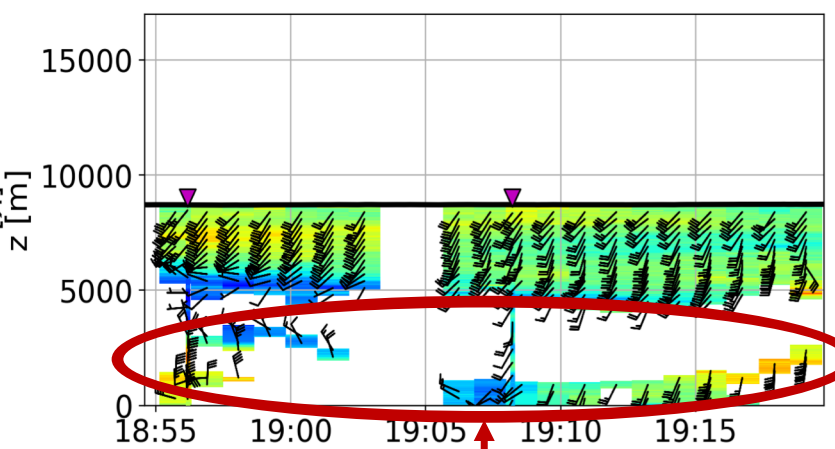
Results

Storm Structure – Genesis

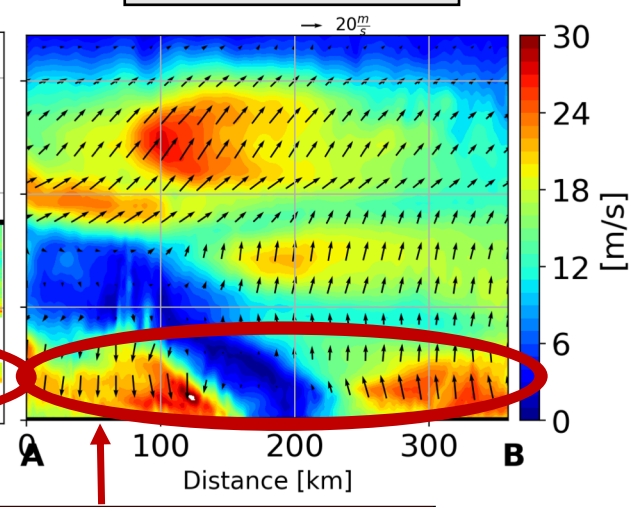
June 20th 19 UTC



CPEX Observations



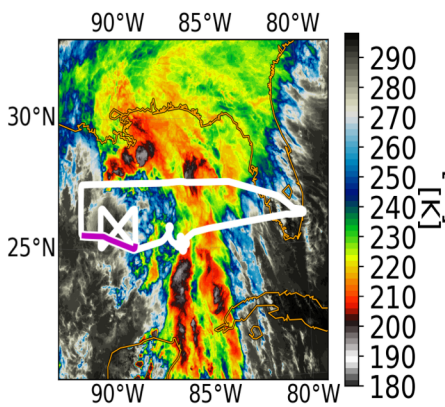
UWINCM



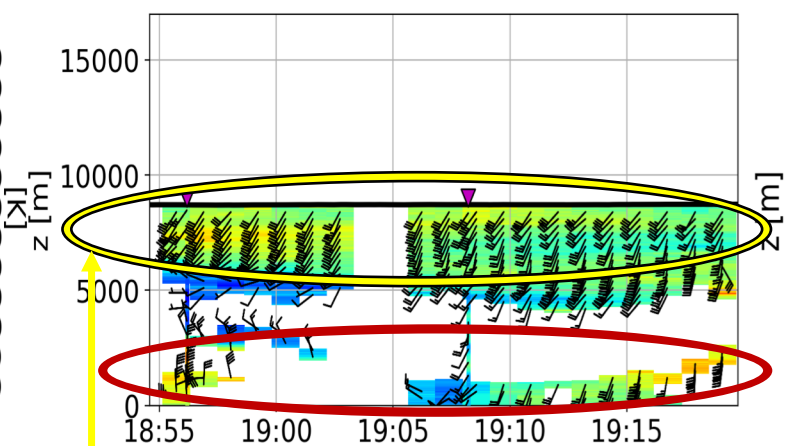
Cyclonic vortex confined below 4 km.

Storm Structure – Genesis

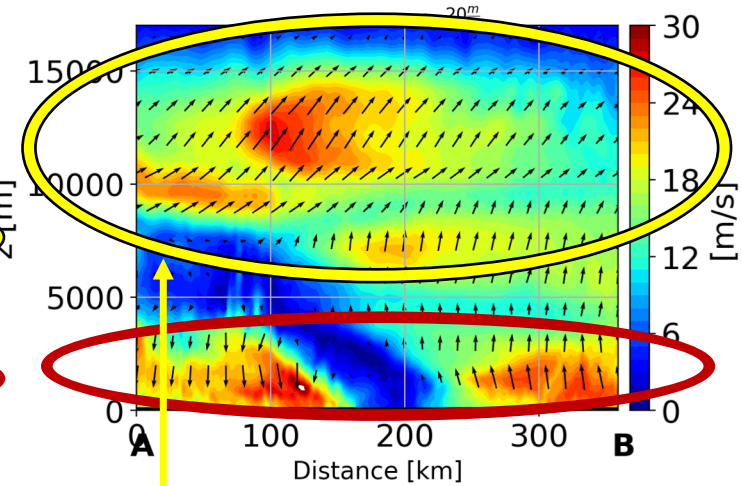
June 20th 19 UTC



CPEX Observations



UWINCM

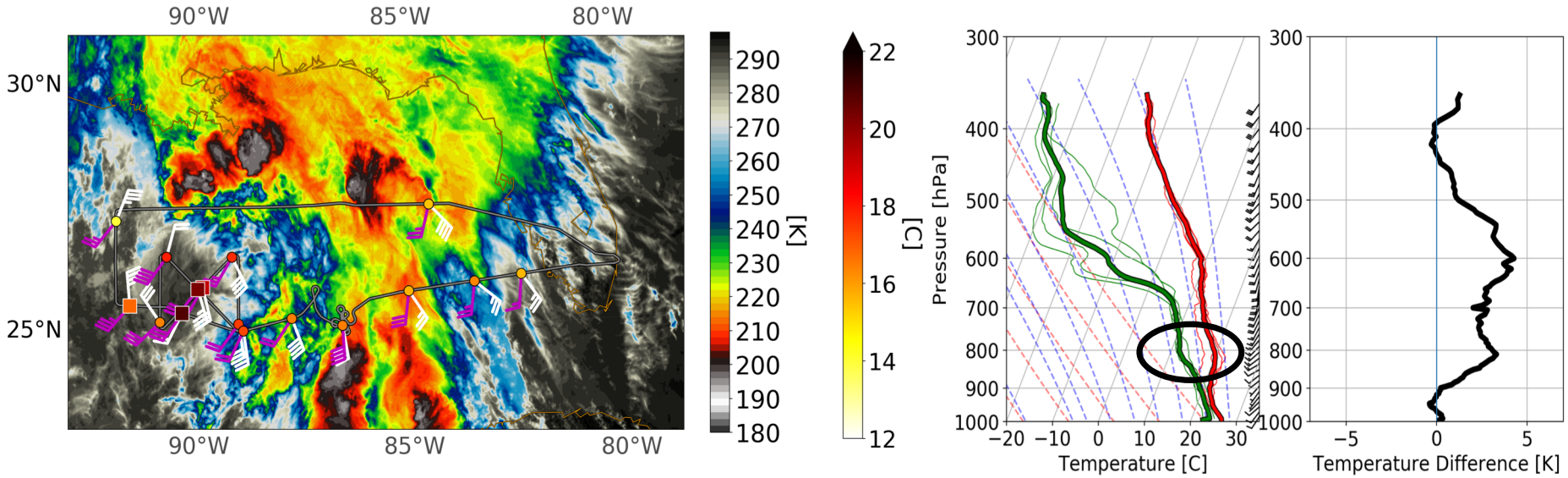


Cyclonic vortex confined below 4 km.

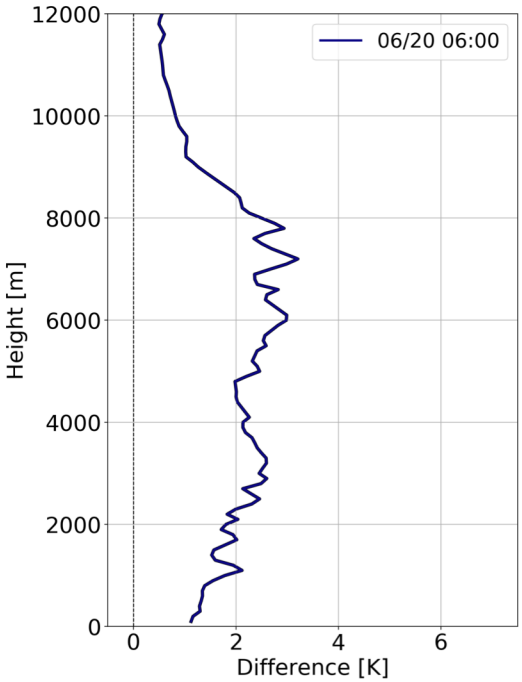
Environmental flow (W/SW) aloft

Observed low-level Warming

- 4 dropsondes near center show ”onion profile”:
  - Large dew point depression, statically neutral (dT/dz ~0)
  - Large T’ at 800 hPa

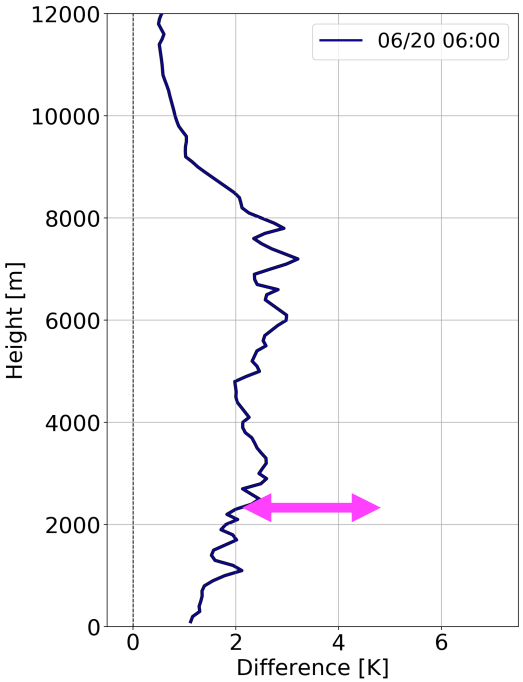


UWIN-CM: Low-level Warming



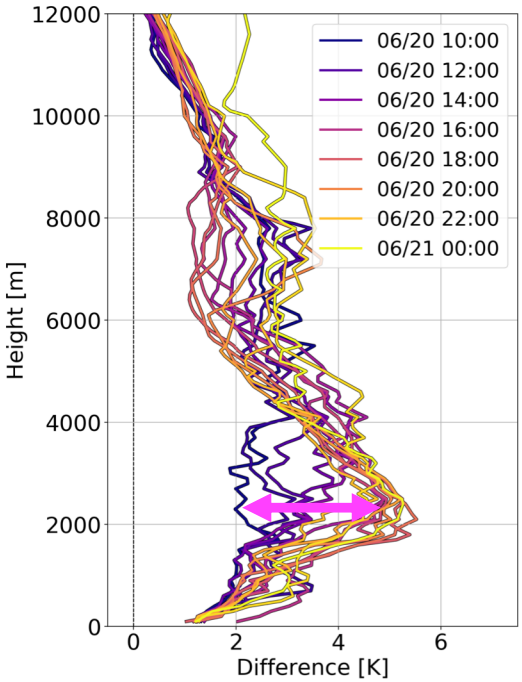
- Max T’ (< 100 km from center)

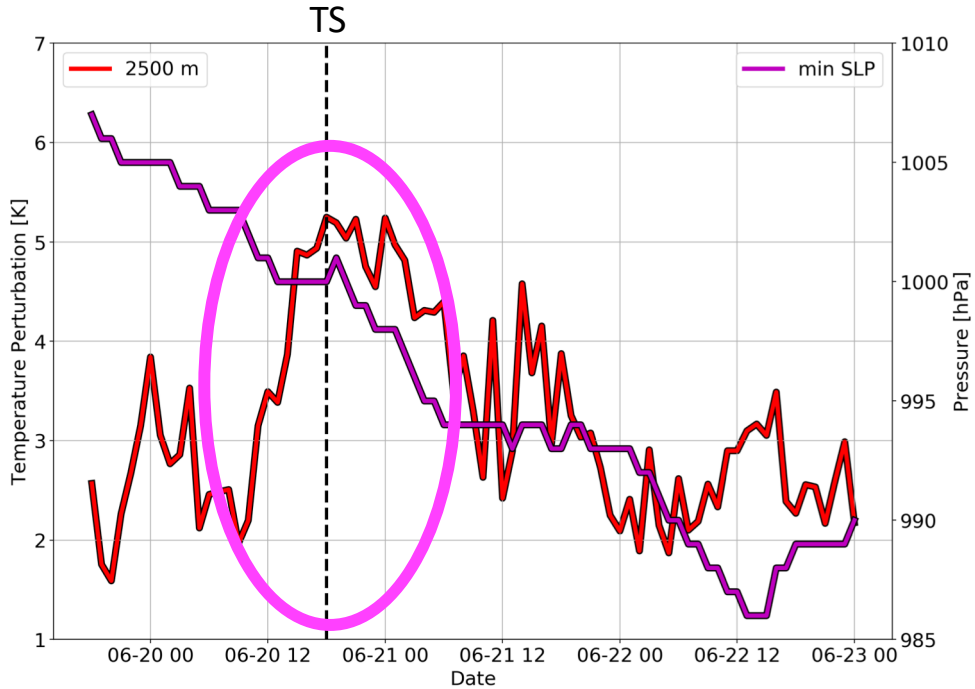
UWIN-CM: Low-level Warming



- Max T’ (< 100 km from center) – 3 K warming ~2.5 km elevation.

UWIN-CM: Low-level Warming

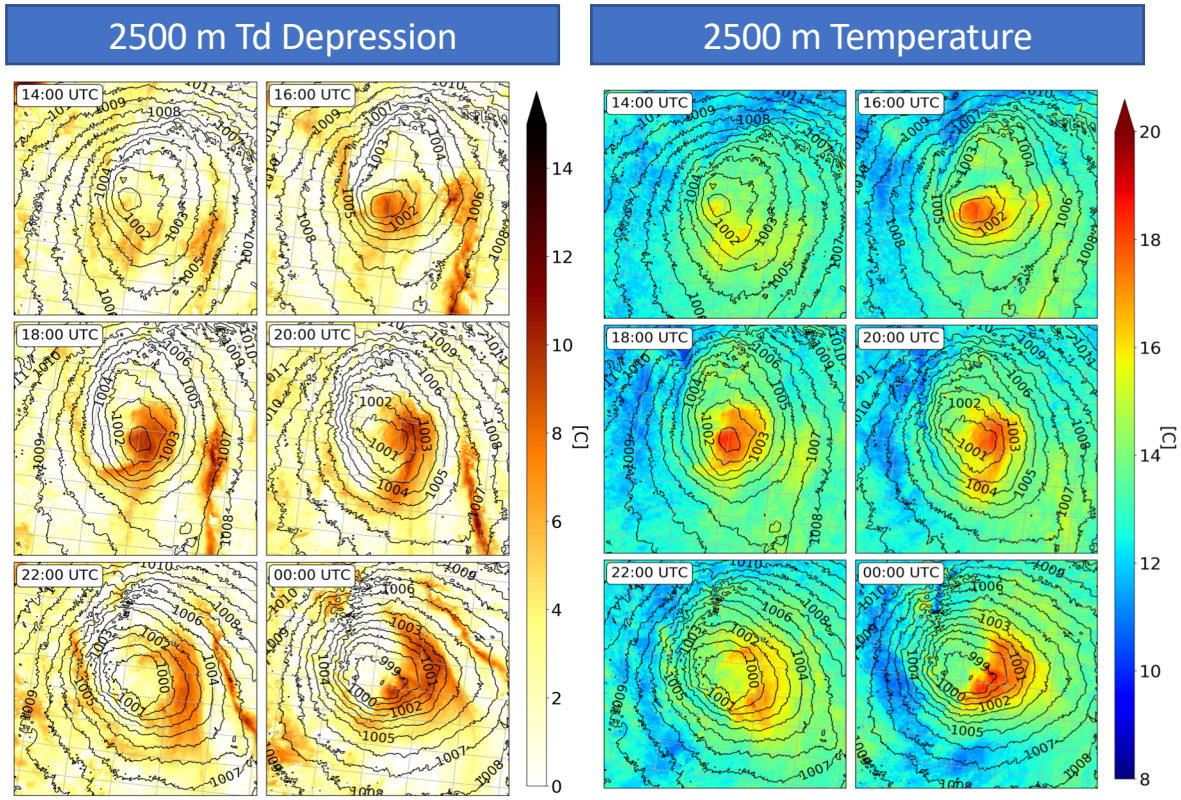




- Max T’ (< 100 km from center) – 3 K warming ~2.5 km elevation.
- Low-level warming occurs during genesis stage.

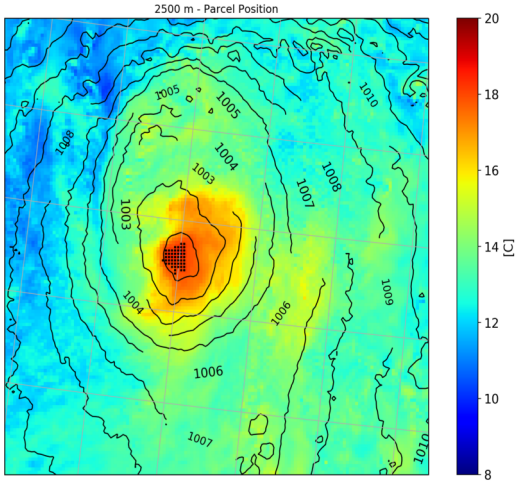
UWIN-CM: Low-level Warming

- Close to SLP minimum: large dew-point depression, positive temperature anomaly.



Subsidence Warming

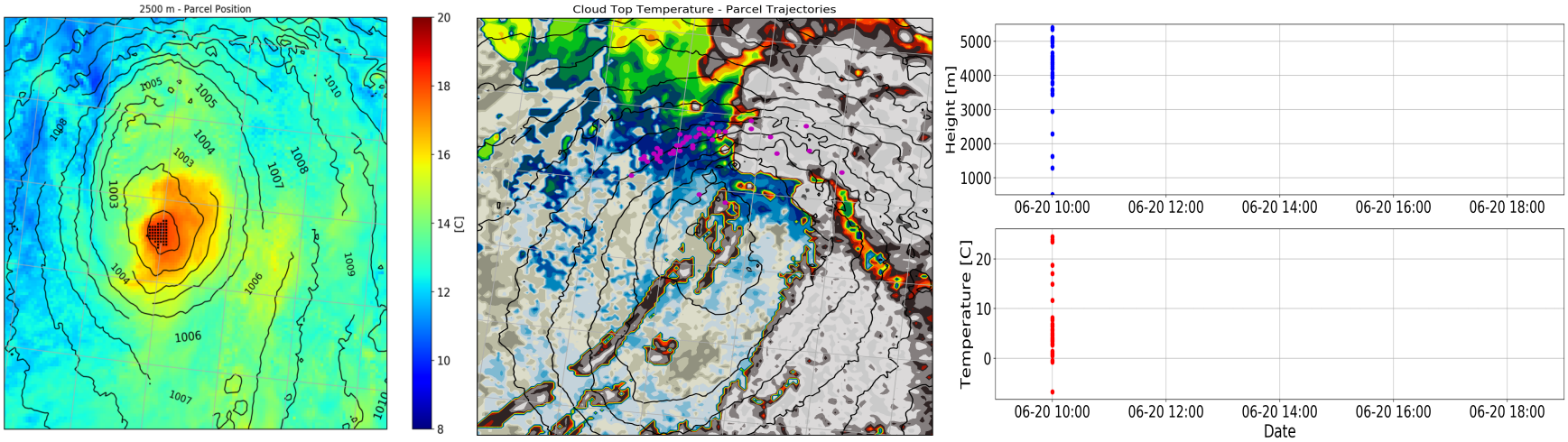
- Backward trajectories from max T’ at 2500 m starting at 1800 UTC.



Median Parcel:

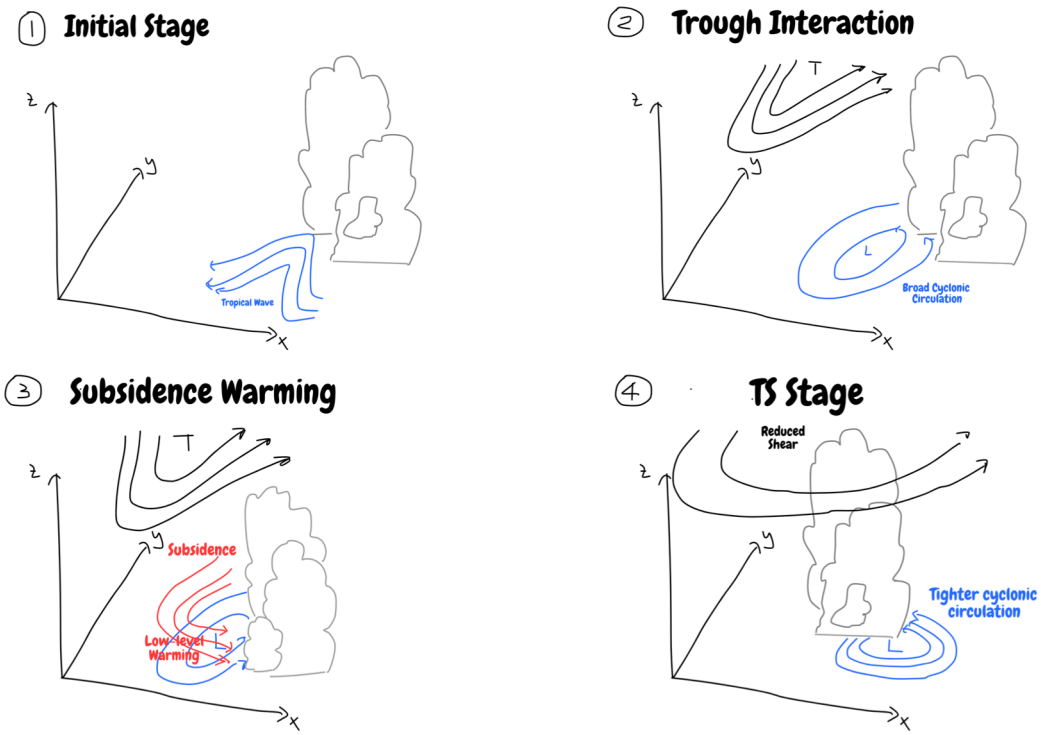
Subsidence Warming

- Backward trajectories from max T’ at 2500 m starting at 1800 UTC.
- Proximity to deep convection suggests help from evaporational cooling.



Median Parcel: dz = -1.8 km, dT = 14 C

TS Cindy - Genesis pathway



Conclusions

- Shallow precursor vortex (< 4km) in high shear.
- During genesis: mesoscale 3K warming between 2-2.5 km.
- 1.5-3.5 km layer accounts for 2.5 hPa (50% of SLP deficit).
- Slanted, downward trajectories in upshear sector: dz ~ 1.8 Km, dT = 14 C.
- Organized mesoscale descent, possibly enhanced by evaporational cooling: lower-tropospheric warming that contributes to SLP fall during TC genesis.

Thank You!

- Time for comments, questions, critiques!

Additional Slides

TC Genesis – Core Warming

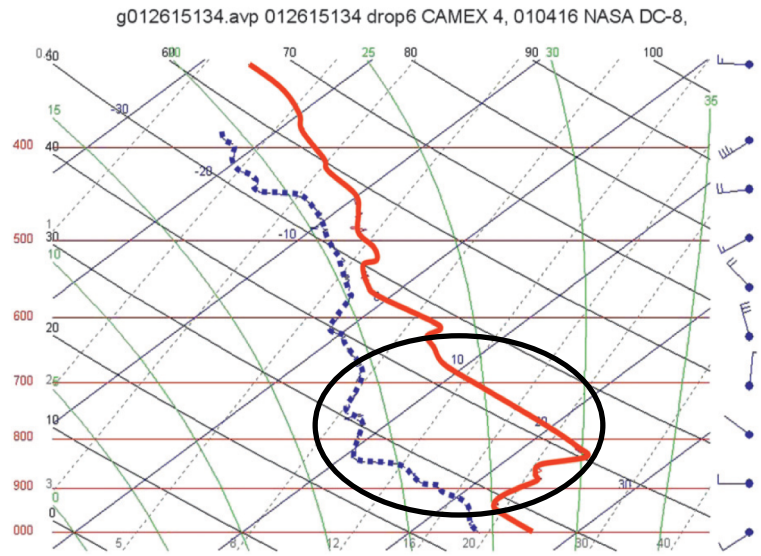
- Warm core height, strength varies from storm to storm.

- Warming from:
  - Latent Heating
  - Subsidence (eye of mature TCs)

- Subsidence observed in tropical squall lines, MCS and during TC genesis.

- Subsidence produces low-level warming (onion profile) and sea-level pressure fall.

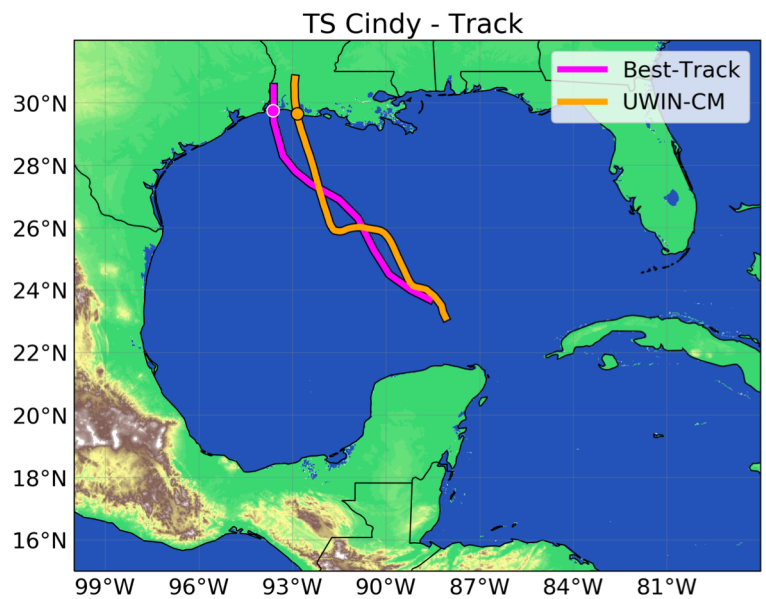
Thermodynamic “onion” profile

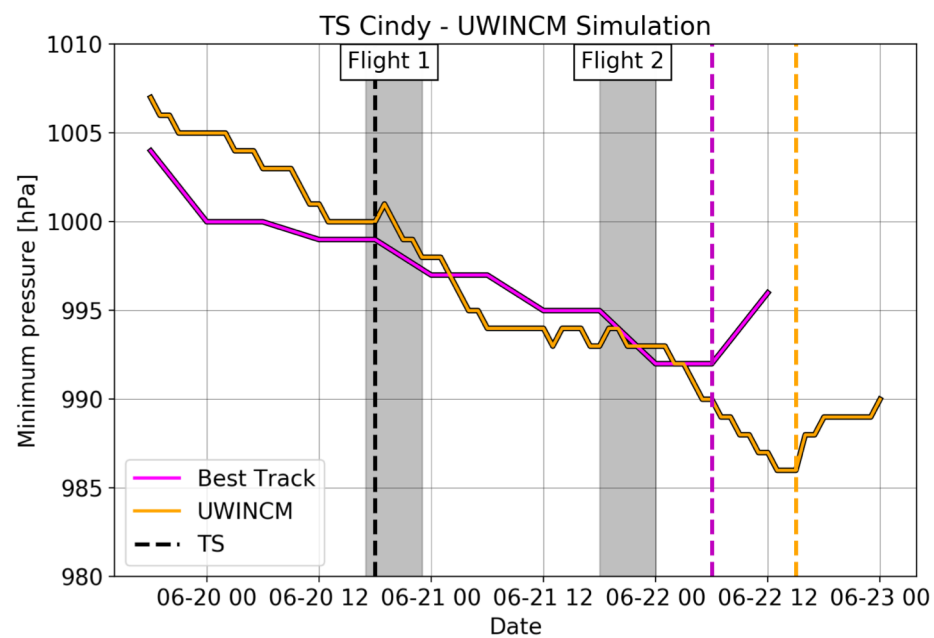


DC-8 dropsonde in Hurricane Humberto (2001) from Dolling and Barnes (2012).

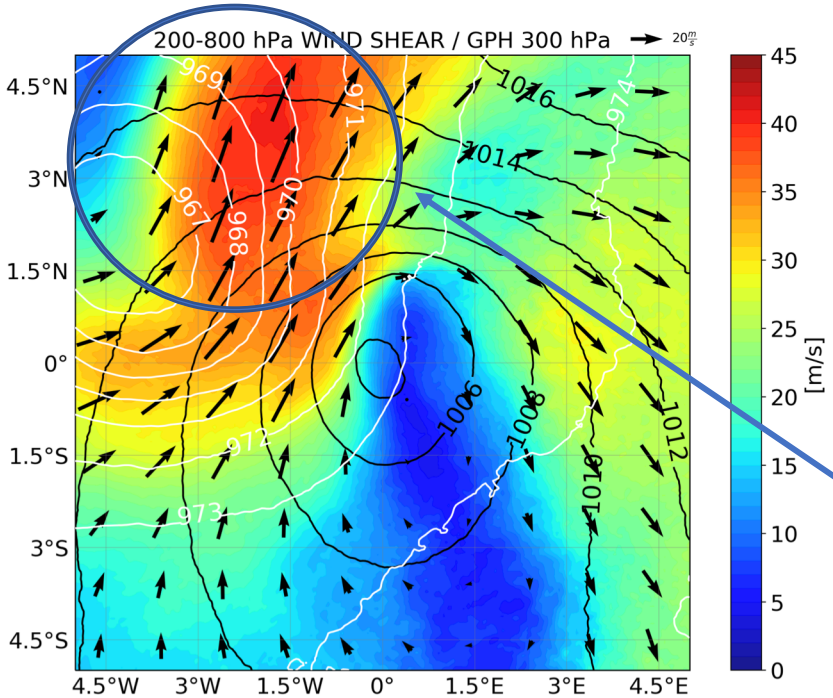
UWIN-CM - Simulation Validation

- Track close to observations, landfall 7 hours later than observed.
- SLP min: 992 hPa (observed) vs. 986 hPa (simulated)





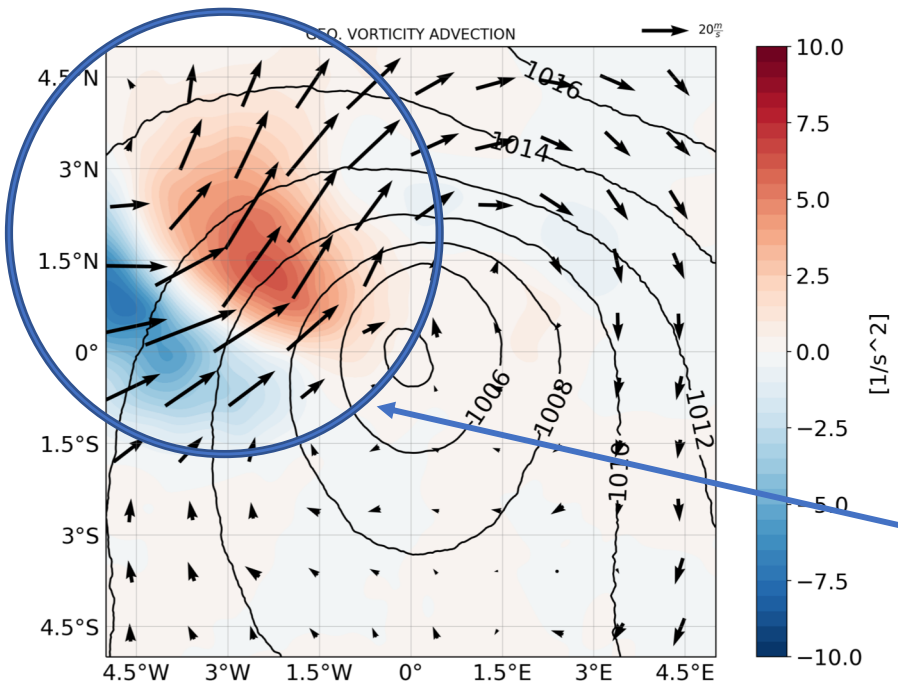
Simulated Large-scale Environment



- Storm-centered composite for 24 hours prior to TC Genesis (06/20 18 UTC).
- Upper-level, cut-off low W/NW of disturbance:

35-40 m/s Wind Shear
+
QG forcing for ascent

Large-scale Environment – QG Forcing

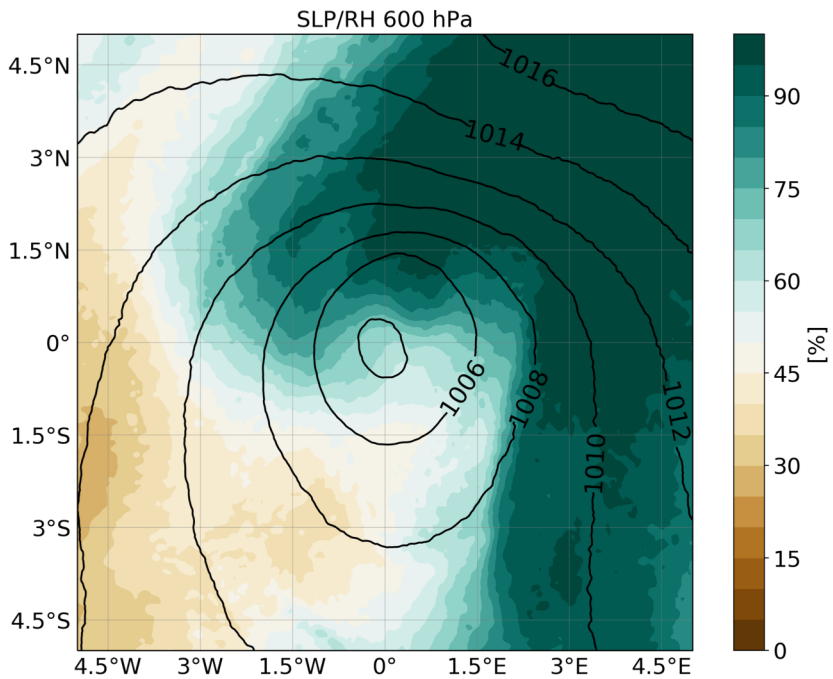


$$\left(\sigma\nabla^2 + f_o^2\frac{\partial^2}{\partial p^2}\right)\omega = 2f\left(-\vec{V}_T\cdot\nabla\zeta_g\right)$$

- Advection of geostrophic vorticity by thermal wind (200-400 hPa mean).

- Forcing for large-scale ascent downstream of trough

Large-scale Environment - Moisture



- 600 hPa relative humidity:

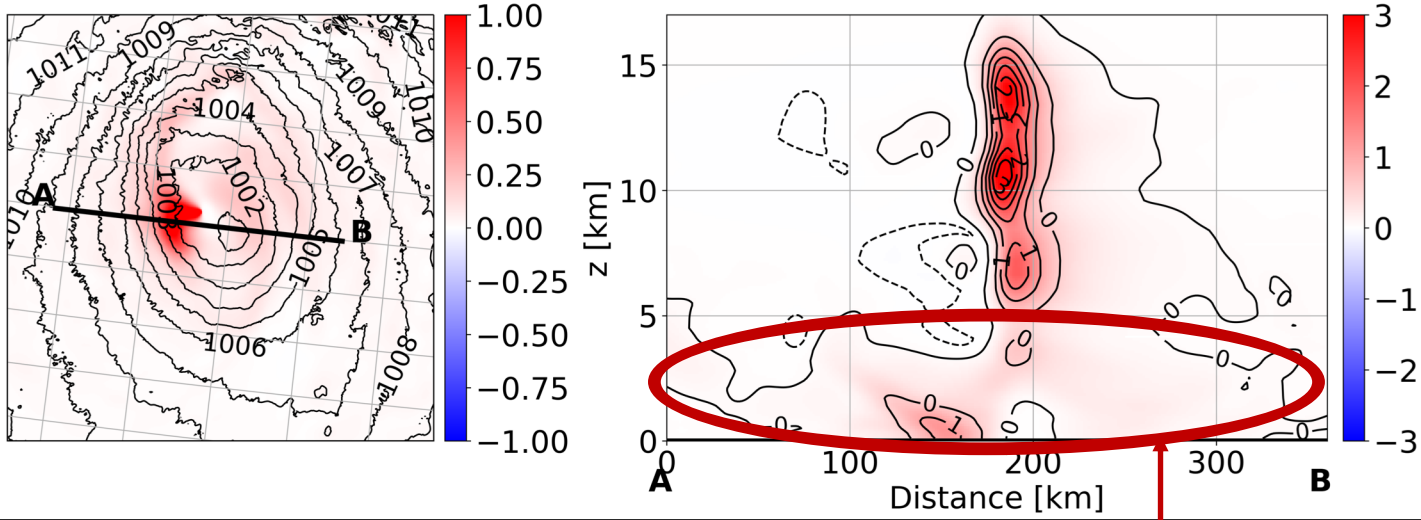
  - E flank: very moist (> 90%)
  - W flank: very dry (<50 %)

4.3 Simulated Inertial Stability

- Tangential wind (v_t) determines inertial stability (I)

$$I^2 = \left(f^2 + \frac{\partial r v_t}{r \partial r}\right)\left(f + \frac{2v_t}{r}\right)$$

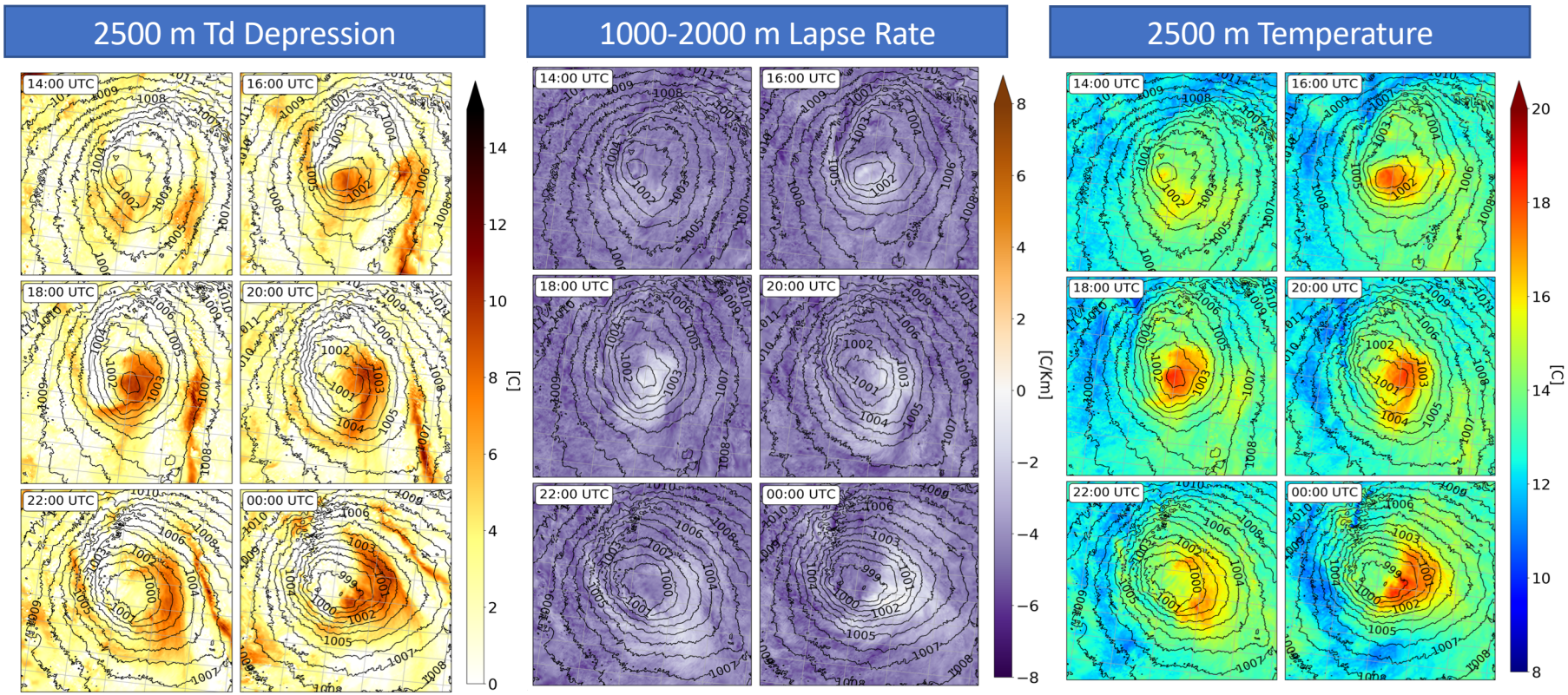
June 20th 19:00 UTC



Inertially stable region below 4 km.

UWIN-CM: Low-level Warming

- Large dew-point depression, increased static stability, temperature perturbation.



UWIN-CM: Hydrostatic adjustment

$$\Delta SLP = \int_{z1}^{z2} \frac{-p(z)\cdot g}{R_d}\left[\frac{1}{\overline{T_v}} - \frac{1}{T_v'}\right] dz$$

- $\overline{T_v}$ = domain-average T_v.
  $T_v{}' = T_v - \overline{T_v}$
- 1.5-3.5 km layer: 2.5 hPa
  ~50% of SLP perturbation.